CHAPTER 1
INTRODUCTION TO RELIABILITY-CENTERED MAINTENANCE

1-1. Purpose

The purpose of this technical manual is provide facility managers with the information and procedures necessary to develop and update a preventive maintenance (PM) program for their facilities that is based on the reliability characteristics of equipment and components and cost. Such a PM program will help to achieve the highest possible level of facility availability at the minimum cost.

1-2. Scope

The information in this manual reflects the commercial practices and lessons learned over many years of developing cost-effective preventive maintenance programs for a wide variety of systems and equipment. It specifically focuses on developing PM programs for electrical and mechanical systems used in command, control, communications, computer, intelligence, surveillance, and reconnaissance (C4ISR) facilities based on the reliability characteristics of those systems and economic considerations, while ensuring that safety is not compromised. The process for developing such a PM program is called Reliability-Centered Maintenance, or RCM. Two appendices develop key topics more deeply: appendix B, statistical distribution; and appendix C, availability.

1-3. References

Appendix A contains a complete list of references used in this manual.

1-4. Availability, maintenance, and reliability

In addition to the following key terms, the glossary lists acronyms, abbreviations, and additional definitions for terms used in this document. Additional terms are included to help the reader better understand the concepts presented herein.

a. *Availability.* (Also see appendix C). Availability is defined as the probability that a system or product will be available to perform its intended mission or function when called upon to do so at any point in time. It can be measured in one of several ways.

(1) *Function of uptime.* Availability can be considered as the percent of total time that a system is available. It is measured using equation 1 (note that the period of time over which this measure of availability is made must be defined). Downtime includes administrative time and delays, as well as time for maintenance and repair.

$$\text{Availability} = \frac{\text{Uptime}}{\text{Downtime} + \text{Uptime}\,(= \text{Total Time})} \qquad \text{Equation 1}$$

(2) *Operational availability.* Another equation for availability directly uses parameters related to the reliability and maintainability characteristics of the item as well as the support system. Equation 2 reflects this measure.

$$\text{Availability} = \frac{\text{Mean Time Between Maintenance (MTBM)}}{\text{Mean Downtime} + \text{MTBM}} \qquad \text{Equation 2}$$

(3) *Inherent availability.* In equation 2, MTBM includes all maintenance required for any reason, including repairs of actual design failures, repairs of induced failures, cases where a failure cannot be confirmed, and preventive maintenance. When only maintenance required to correct design failures are counted and the effects of the support system are ignored, the result is *inherent availability*, which is given by equation 3.

$$\text{Availability} = \frac{\text{Mean Time Between Failure (MTBF)}}{\text{Mean Time to Repair} + \text{MTBF}} \qquad \text{Equation 3}$$

b. *Maintenance.* Maintenance is defined as those activities and actions that directly retain the proper operation of an item or restore that operation when it is interrupted by failure or some other anomaly. (Within the context of RCM, proper operation of an item means that the item can perform its intended function.) These activities and actions include removal and replacement of failed items, repair of failed items, lubrication, servicing (includes replenishment of consumables such as fuel), and calibrations. Other activities and resources are needed to support maintenance. These include spares, procedures, labor, training, transportation, facilities, and test equipment. These activities and resources are usually referred to as logistics. Although some organizations may define maintenance to include logistics, it will be used in this TM in the more limited sense and will not include logistics.

(1) Corrective maintenance. Corrective maintenance is maintenance required to restore a failed item to proper operation. Restoration is accomplished by removing the failed item and replacing it with a new item, or by fixing the item by removing and replacing internal components or by some other repair action.

(2) *Preventive maintenance.* Scheduled maintenance or maintenance performed based on the condition of an item conducted to ensure safety, reduce the likelihood of operational failures, and obtain as much useful life as possible from an item.

(3) *Condition-based maintenance.* Condition-based maintenance can be performed on the basis of observed wear or on predicting when the risk of failure is excessive.

(a) Some items exhibit wear as they are used. If the probability of failure can be related to a measurable amount of wear, it may be possible to prescribe how much wear can be tolerated before the probability of failure reaches some unacceptable level. If so, then this point becomes the criterion for removal or overhaul. Measurement can be done using a variety of techniques depending on the characteristic being measured. The length of cracks in structures, for example, can be measured using x-ray and ultrasound.

(b) In predictive maintenance, a given operating characteristic of the item, vibration or temperature, for example, is trended and compared with the known "normal" operating levels. An acceptable range is established with either upper and lower limits, or some maximum or minimum level. As long as the trend data remain inside the acceptable level, any variation is considered to be normal variation due to variances in materials, operating environment, and so forth. When the trend line intersects the "unacceptable" limit line, preventive maintenance is required to prevent a failure in the future. The limits are based on knowledge of the normal operating characteristics and the level of risk of failure we are willing to accept.

c. *Reliability.* The probability that an item will perform its intended function(s) without failure for a specified time under stated conditions.

d. *Reliability-centered maintenance (RCM).* RCM is a logical, structured framework for determining the optimum mix of applicable and effective maintenance activities needed to sustain the operational reliability of systems and equipment while ensuring their safe and economical operation and support. Although RCM focuses on identifying preventive maintenance actions, corrective actions are identified by default. That is, when no preventive action in effective or applicable for a given item, that item is run to failure (assuming safety is not at issue). From that perspective, RCM identifies all maintenance. RCM is focused on optimizing readiness, availability, and sustainment through effective and economical maintenance.

1-5. The reliability-centered maintenance concept

Prior to the development of the RCM methodology, it was widely believed that everything had a "right" time for some form of preventive maintenance (PM), usually replacement or overhaul. A widespread belief among many maintenance personnel was that by replacing parts of a product or overhauling the product (or reparable portions thereof), that the frequency of failures during operation could be reduced. Despite this previous commonly held view, the results seemed to tell a different story. In far too many instances, PM seemed to have no beneficial effects. Indeed, in many cases, PM actually made things worse by providing more opportunity for maintenance-induced failures.

a. *Airline study.* When the airline companies in the United States observed that PM did not always reduce the probability of failure and that some items did not seem to benefit in any way from PM, they formed a task force with the Federal Aviation Administration (FAA) to study the subject of preventive maintenance. The results of the study confirmed that PM was effective only for items having a certain pattern of failures. The study also concluded that PM should be required only when required to assure safe operation. Otherwise, the decision to do or not do PM should be based on economics.

b. *RCM approach.* The RCM approach provides a logical way of determining if PM makes sense for a given item and, if so, selecting the appropriate type of PM. The approach is based on the following precepts.

(1) *The objective of maintenance is to preserve an item's function(s).* RCM seeks to preserve system or equipment function, not just operability for operability's sake. Redundancy improves functional reliability but increases life cycle cost in terms of procurement and life cycle cost.

(2) *RCM focuses on the end system.* RCM is more concerned on maintaining system function than individual component function.

(3) *Reliability is the basis for decisions.* The failure characteristics of the item in question must be understood to determine the efficacy of preventive maintenance. RCM is not overly concerned with simple failure rate; it seeks to know the conditional probability of failure at specific ages (the probability that failure will occur in each given operating age bracket).

(4) *RCM is driven first by safety and then economics.* Safety must always be preserved. When safety is not an issue, preventive maintenance must be justified on economic grounds.

(5) *RCM acknowledges design limitations.* Maintenance cannot improve the inherent reliability – it is dictated by design. Maintenance, at best, can sustain the design level of reliability over the life of an item.

(6) *RCM is a continuing process.* The difference between the perceived and actual design life and failure characteristics is addressed through age (or life) exploration.

c. *RCM concept.* The RCM concept has completely changed the way in which PM is viewed. It is now a widely accepted fact that not all items benefit from PM. Moreover, even when PM would be effective, it is often less expensive (in all senses of that word) to allow an item to "run to failure" rather than to do PM. In the succeeding discussions, we will examine the RCM concept in more detail. We will explore the meaning of terms that are central to the RCM approach. These terms include failure characteristics, efficiency, run to failure, cost, and function.

1-6. Benefits of RCM

a. *Reduced costs.* A significant reason for creating the aforementioned joint airline/FAA task force was the new Boeing 747 (B747) jumbo jet. Boeing and United Airlines, the initial buyer of the aircraft, were already considering the development of the PM program for the B747. This new airliner was vastly larger and more complex than any ever built. Given the cost of maintenance on smaller aircraft already in service, the maintenance costs for the B747, using the traditional approach to PM, would have threatened the profitability, and hence the viability, of operating the new aircraft. Examples of the ultimate savings achieved in using RCM to develop the PM program for the B747 and other aircraft are shown in table 1-1. Similar savings have been achieved by other industries for other equipment when going from a traditional to an RCM-based PM program. It is important to note that these costs savings are achieved with no reduction in safety, an obvious requirement in the airline industry.

Table 1-1. Cost benefits of using RCM for developing PM program

Type of PM	Required Using Traditional Approach	Required Using RCM
Structural inspections	4,000,000 hours for DC-8	66,000 hours for B747
Overhaul	339 items for DC-8	7 items for DC-10
Overhaul of turbine engine	Scheduled	On-condition (cut shop maintenance costs by 50% compared with DC-8)

b. *Increased availability.* For many systems, including C4ISR facilities, availability is of primary importance. Availability was defined in paragraph 1-4. As indicated in the definition, the level of availability achieved in actual use of a product is a function of how often it fails and how quickly it can be restored to operation. The latter, in turn, is a function of how well the product was designed to be maintainable, the amount of PM required, and the logistics resources and infrastructure that have been put in place to support the product. RCM directly contributes to availability by reducing PM to that which is essential and economic.

1-7. Origins of RCM

a. *Airlines.* As stated earlier, RCM had its origins with the airline industry. Nowhere had the then-prevailing philosophy of maintenance been challenged more. By the late 1950's, maintenance costs in the industry had increased to a point where they had become intolerable. Meanwhile, the Federal Aviation Agency (FAA) had learned through experience that the failure rate of certain types of engines could not be controlled by changing either the frequency or the content of scheduled fixed-interval overhauls. As a result of these two factors, a task force consisting of representatives of the airlines and aircraft manufacturers was formed in 1960 to study the effectiveness of PM as being implemented within the airline industry.

(1) *The task force.* The task force developed a rudimentary technique for developing a PM program. Subsequently, a maintenance steering group (MSG) was formed to manage the development of the PM program for the new Boeing 747 (B747) jumbo jet. This new airliner was vastly larger and more complex than any ever built. Given the cost of maintenance on smaller aircraft already in service, the maintenance costs for the B747, using the traditional approach to PM, would have threatened the profitability, and hence the viability, of operating the new aircraft.

(2) *MSG-1.* The PM program developed by the steering group, documented in a report known as MSG-1, was very successful. That is, it resulted in an affordable PM program that ensured the safe and profitable operation of the aircraft.

(3) *MSG-2.* The FAA was so impressed with MSG-1 that they requested that the logic of the new approach be generalized, so that it could be applied to other aircraft. So in 1970, MSG-2, Airline Manufacturer Maintenance Program Planning Document, was issued. MSG-2 defined and standardized the logic for developing an effective and economical maintenance program. MSG-2 was first used on the L1011, DC10, and MD80 aircraft. In 1972, the European aviation industries issued EMSG (European Maintenance System Guide), which improved on MSG-2 in the structures and zonal analysis. EMSG was used on the Concorde and A300 Airbus.

b. *Adoption by military.* The problems that the airlines and FAA had experienced with the traditional approach to maintenance were also affecting the military. Although profit was not an objective common to both the airlines and military, controlling costs and maximizing the availability of their aircraft were. Consequently, in 1978, the DOD contracted with United Airlines to conduct a study into efficient maintenance programs. The study supplemented MSG-2 by emphasizing the detection of hidden failures and moved from a process-oriented concept to a task-oriented concept. The product of the study was MSG-3, a decision logic that was called Reliability-Centered Maintenance (RCM).

c. *Use for facilities and other industries.* Although created by the aviation industry, RCM quickly found applications in many other industries. RCM is used to develop PM programs for public utility plants, especially nuclear power plants, railroads, processing plants, and manufacturing plants. It is no overstatement to say that RCM is now the pre-eminent method for evaluating and developing a comprehensive maintenance program for an item. Today, a variety of documents are available on RCM. A listing of some of the more prominent documents is included in appendix A.

1-8. Relationship of RCM to other disciplines

a. *Reliability.* It is obvious why the first word in the title of the MSG-3 approach is reliability. Much of the analysis needed for reliability provides inputs necessary for performing an RCM analysis, as will be seen in succeeding sections. The fundamental requirement of the RCM approach is to understand the failure characteristics of an item. As used herein, failure characteristics include the underlying probability density function, the consequences of failure, and whether or not the failure manifests itself and, if it does, how. Reliability is measured in different ways, depending on one's perspective: inherent reliability, operational reliability, mission (or functional) reliability, and basic (or logistics) reliability. RCM is related to operational reliability.

(1) *Inherent versus operational reliability.* From a designer's perspective, reliability is measured by "counting" only those failures that are design-related. When measured in this way, reliability is referred to as "inherent reliability." From a user's or operator's perspective, all events that cause the system to stop performing its intended function is a failure event. These events certainly include all design-related failures that affect the systems' function. Also included are maintenance-induced failures, no-defect found events, and other anomalies that may have been outside the designer's contractual responsibility or technical control. This type of reliability is called "operational reliability."

(2) *Mission or functional reliability versus basic or logistics reliability.* Any failure that causes the product to fail to perform its function or mission is counted in "mission reliability." Redundancy improves mission reliability. Consider a case where one part of a product has two elements in parallel where only one is needed (redundant). If a failure of one element of the redundant part of the product fails, the other continues to function allowing the product to do its job. Only if both elements fail will a mission failure occur. In "basic" reliability, all failures are counted, whether or not a mission or functional failure has occurred. This measure of reliability reflects the total demand that will eventually be placed on maintenance and logistics.

b. *Safety.* Earlier, it was stated that one of the precepts on which the RCM approach is that safety must always be preserved. Given that the RCM concept came out of the airline industry, this emphasis on ensuring safety should come as no surprise. In later sections, the manner in which the RCM logic ensures that safety is ensured will be discussed. For now, it is sufficient to note that the RCM specifically addresses safety and is intended to ensure that safety is never compromised. In the past several years, environmental concerns and issues involving regulatory bodies have been accorded an importance in the RCM approach for some items that is equal (or nearly so) to safety. Failures of an item that can cause damage to the environment or which result in some Federal or state law being violated can pose serious consequences for the operator of the item. So the RCM logic is often modified, as it is in this TM, to specifically address environmental or other concerns.

c. *Maintainability.* RCM is a method for prescribing PM that is effective and economical. Whether or not a given PM task is effective depends on the reliability characteristics of the item in question. Whether or not a task is economical depends on many factors, including how easily the PM tasks can be performed. Ease of maintenance, corrective or preventive, is a function of how well the system has been designed to be maintainable. This aspect of design is called maintainability. Providing ease of access, placing items requiring PM where they can be easily removed, providing means of inspection, designing to reduce the possibility of maintenance-induced failures, and other design criteria determine the maintainability of a system.